Spaceborne Infrared Atmospheric Sounder – GEO (SIRAS-G)

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Ball Aerospace & Technologies Corp

AIRS Science Team Meeting

March 30, 2007

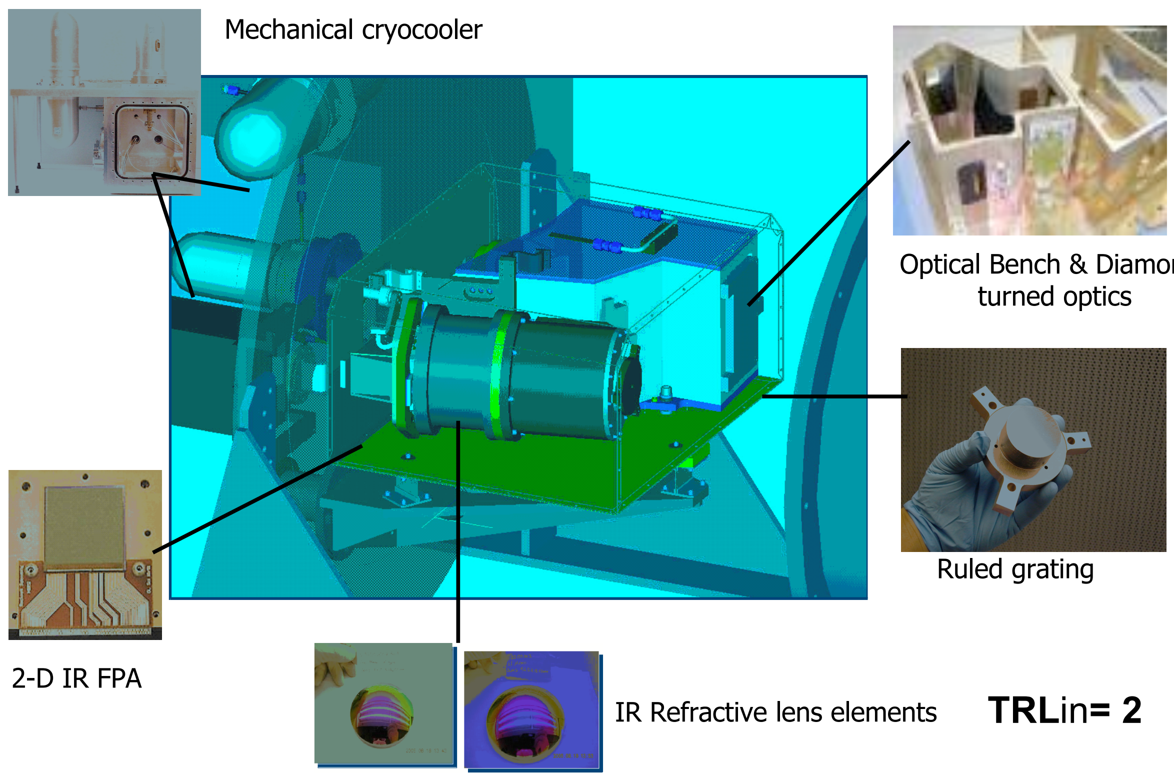
SIRAS-G Instrument Incubator Overview and Objectives

- **Objective**
  - Develop instrument technology for IR atmospheric sounding from GEO and LEO
  - Validate operational performance in a laboratory demonstration
  - Generate a design recommendation for space flight instrument

SIRAS-G IIP
Awarded in 2003

Technology Development Partners:

NASA/Jet Propulsion Laboratory

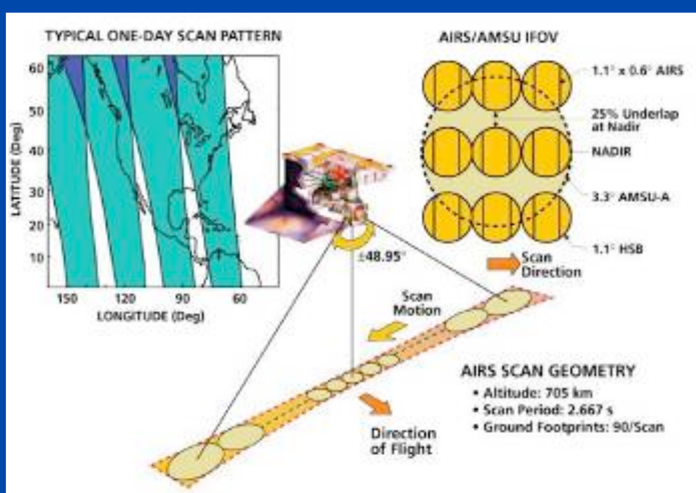


TRLin= 2 TRL current= 4

Evolution of the SIRAS-G Program

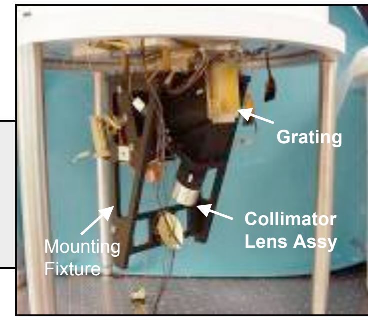
AIRS

- The Atmospheric Infrared Sounder (AIRS) provides 3-dimensional maps of air and surface temperature, water vapor, and cloud properties.
- AIRS has 2378 spectral channels, AIRS has a spectral resolution more than 100 times greater than previous IR sounders



SIRAS-1999

- Ball supported JPL
- Designed, built & cryogenically tested 12-15.4um spectrometer
- Integrated AIRS detector array
- Developed test facilities for testing the spectrometer at cryogenic temperatures



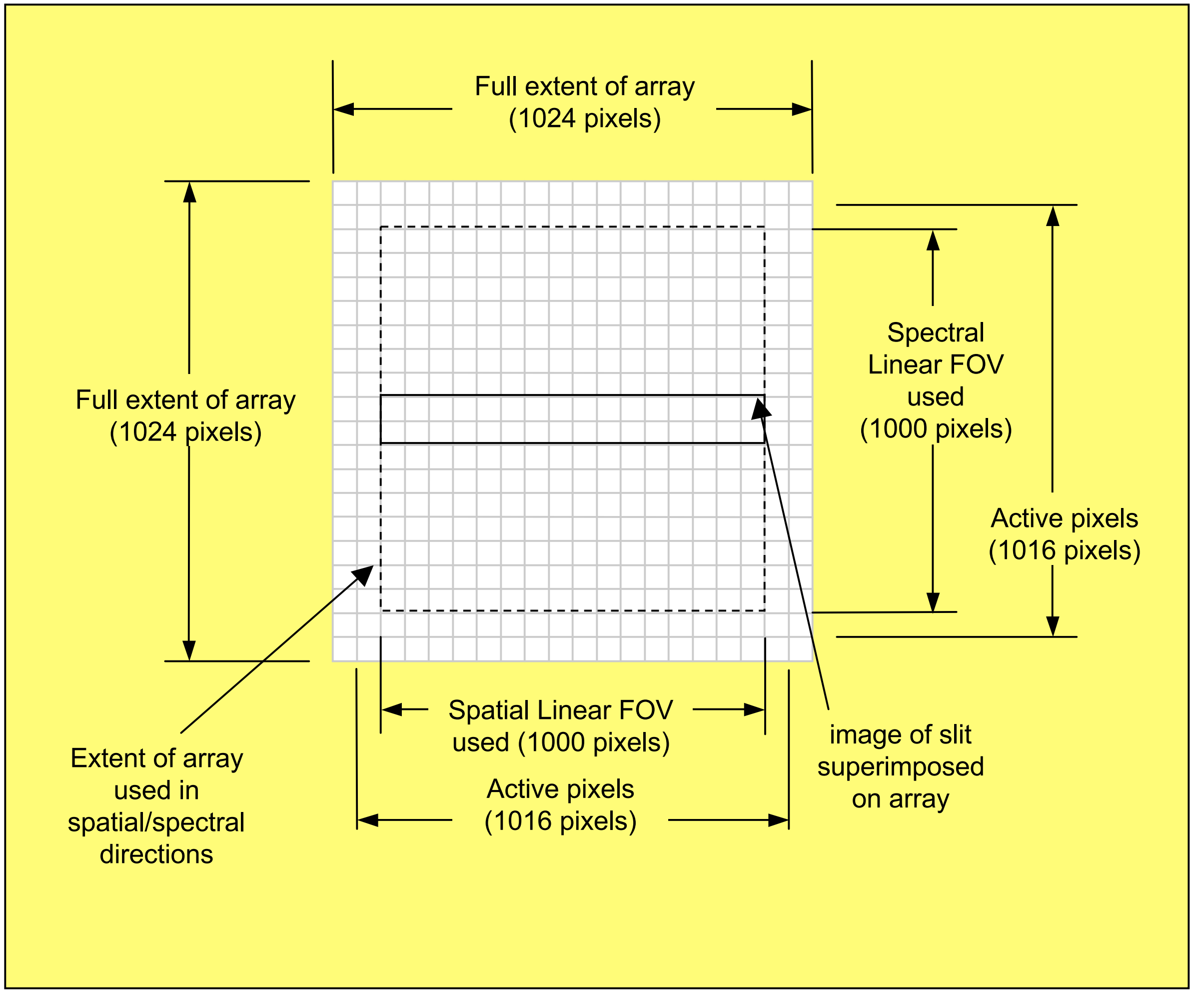
SIRAS-1999 Spectrometer In Test Dewar

SIRAS-G

- Builds on the success of SIRAS-1999
- Demonstrates a complete IR imaging spectrometer operating over the 3.4 – 4.9 um region
- Laboratory demo instrument incorporates a 4-mirror reflective collimator, a 4-element refractive camera, a flat grating, and a large area FPA
- Instrument concept uses several spectrometers to provide full coverage from 3.4 – 15.4 um

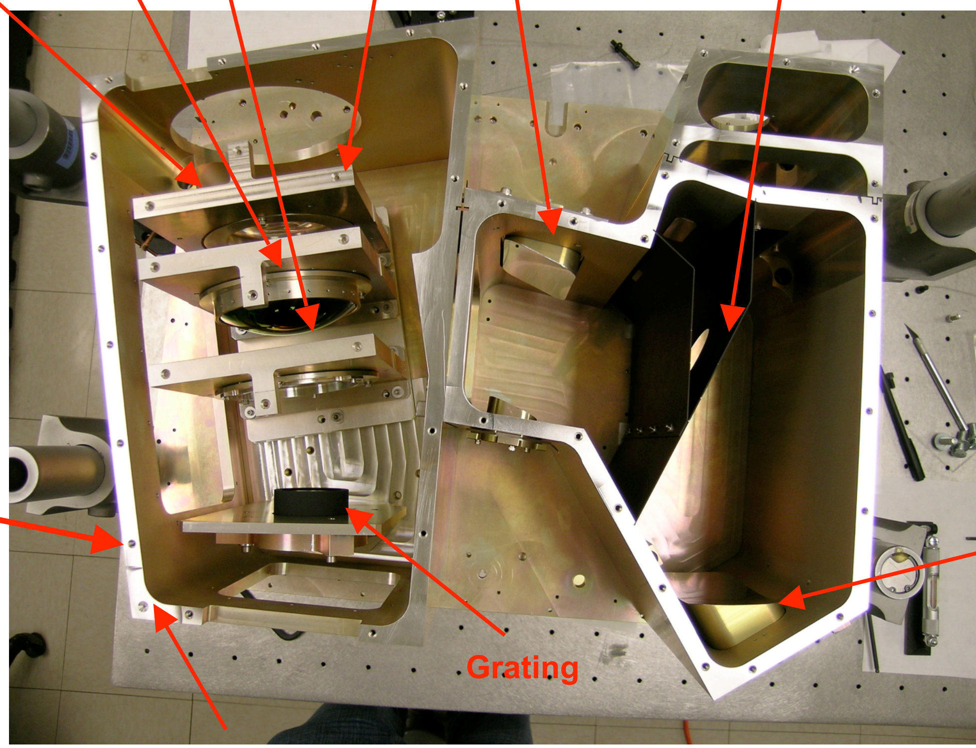
Demo Instrument Optimized for Large Format Array

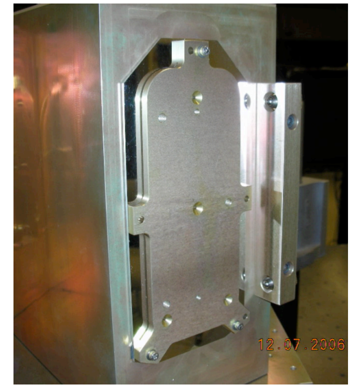
- Teledyne Hawaii 1-RG Array
- 1024 x 1024 Format Array
- 0.018-um Pixel Pitch
- Spatial and spectral resolution elements = 2 pixels
- Image of slit is smaller in length than FPA:
  - Avoids illuminating inactive pixels or leads & wires around FPA
  - Provides margin for alignment of FPA to slit
  - Since ends of slit are on active pixels, alignment of the slit can be measured
  - Simplifies alignment of FPA to detector housing and optical system



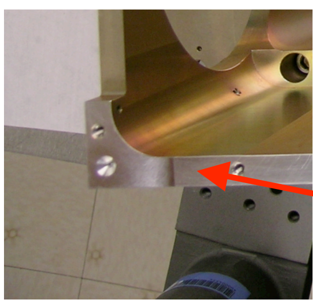
Alignment Fiducials in SIRAS-G OBA

Correct placement of alignment fiducials is critical for efficient assembly





Mirror Fiducial Detail



Fiducial Detail

Camera Lens Elements Bonded into Separate Cells

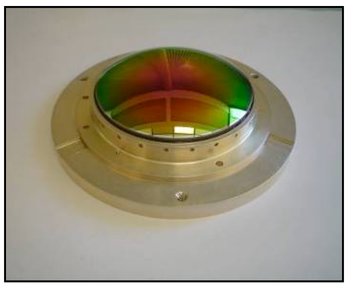
- The refractive lens elements for the camera were fabricated by ISP Optics
- Delivered on 8/15/2005
- All elements meet requirements
- As-built data will be used to re-optimize system prior to assembly
- Lens elements bonded using Dow Corning 93-500 Silicone Adhesive
- Low out-gassing
- Wide operational temperature range: Remains compliant to 100 K
- Extensive BATC heritage
- Bond thicknesses and widths sized to minimize stress with temperature

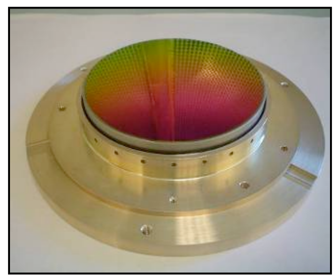
Germanium

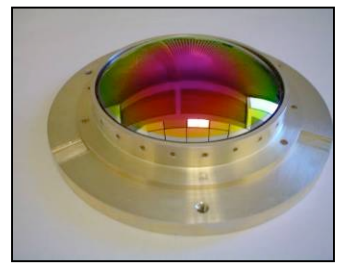
Silicon

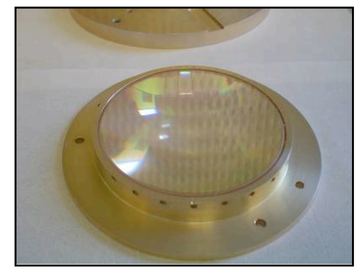
Germanium

Cleartran (ZnS)







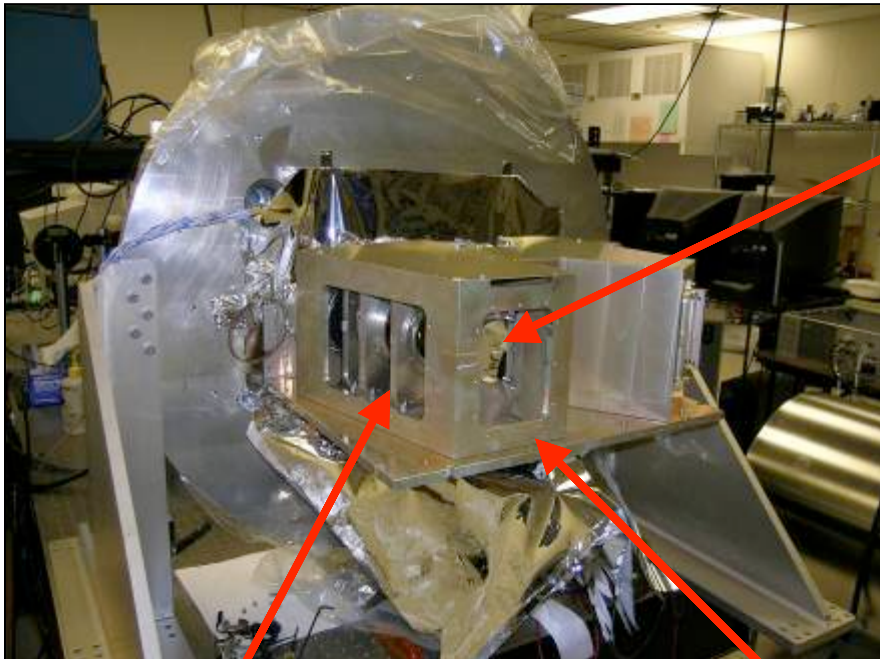


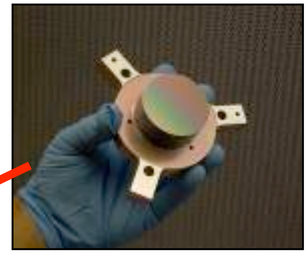
Athermal mount design approach documented in SPIE paper: Herbert, J. (2006), Proc. SPIE Vol. 6288, 62880J, Current Developments in Lens Design and Optical Engineering VII; Pantazis Z. Mouroulis, Warren J. Smith, R. Barry Johnson; Eds.

Element	Bondline Thickness determined from Deluzio Equation
Lens 1 Ge, 86 mm dia.	0.037”
Lens 2 Si, 92 mm dia.	0.048”
Lens 3 Ge, 92 mm dia.	0.040”
Lens 4 ZnS, 72 mm dia.	0.030”

Laboratory Demo Instrument Completed

All Major Hardware Subsystems have been integrated into the Laboratory Demo Instrument

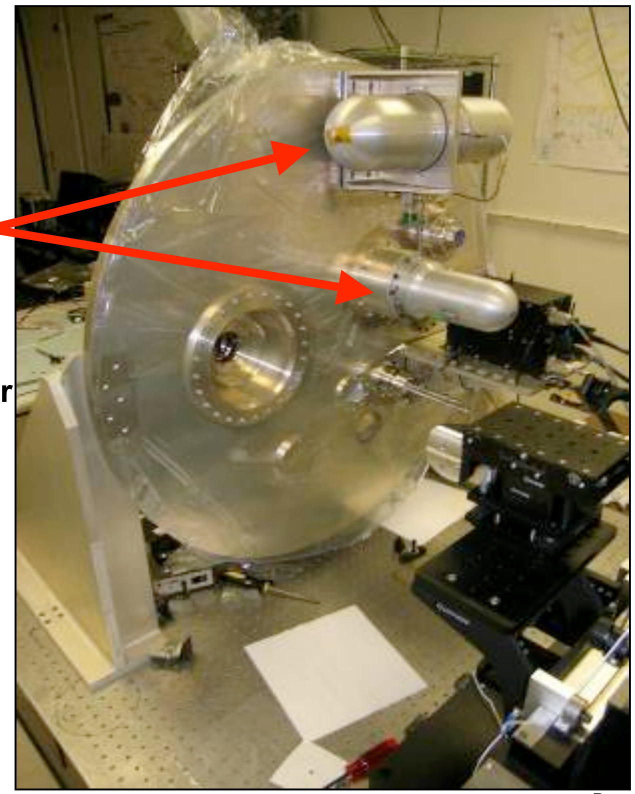




Flat Ruled Grating

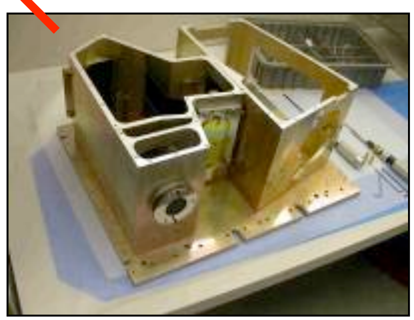
SIRAS-G Flight-like FPA Package

SB-235 CryoCooler



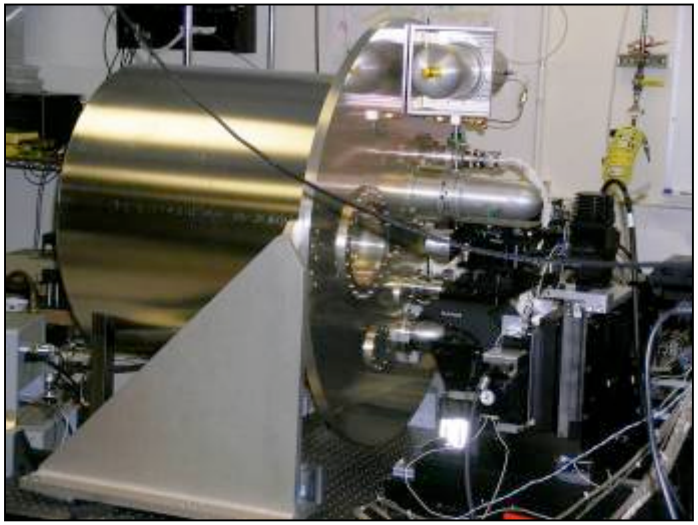
WFOV Refractive Camera

SIRAS-G Aft-Optics Assy

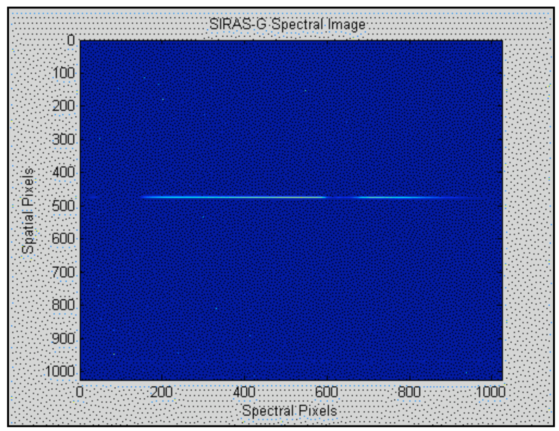


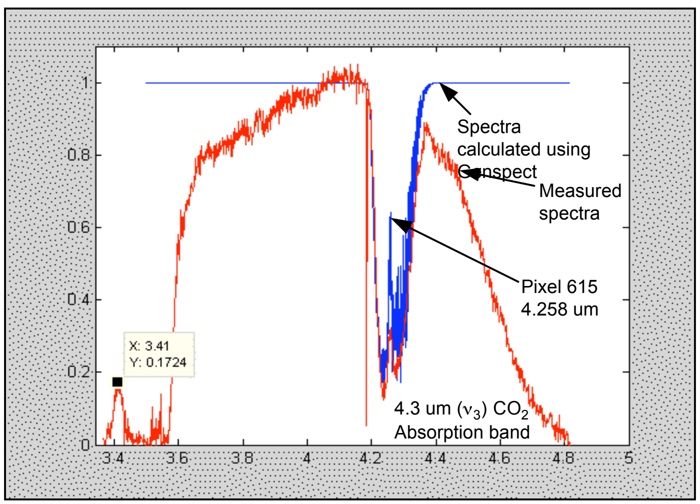
Optical Bench

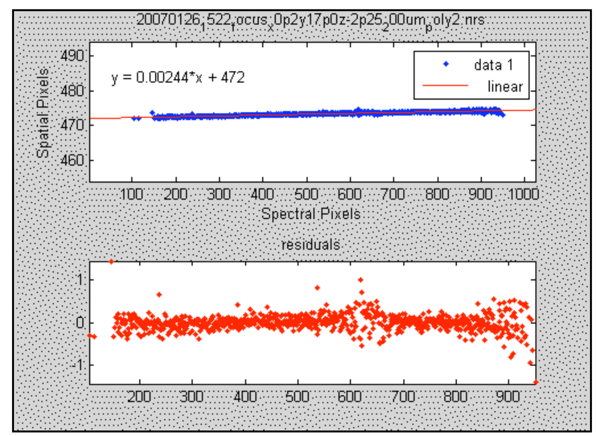
Desired Performance Achieved in Cryogenic Testing



- Measurements show low spectral smile and keystone distortion
- Dispersed MWIR spectrum obtained by SIRAS-G Demo Instrument

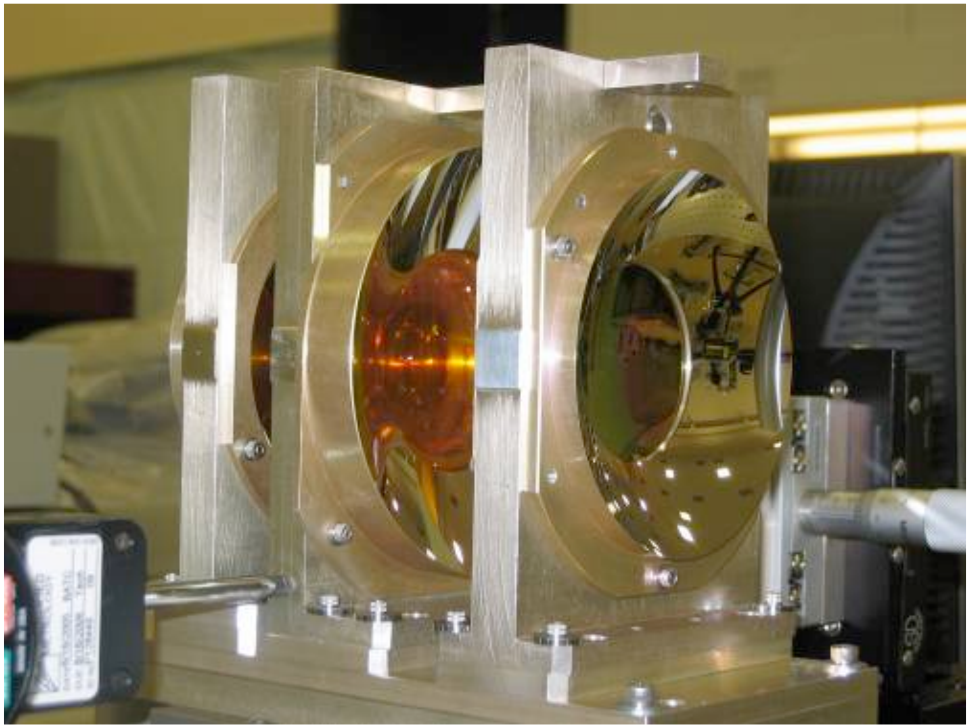






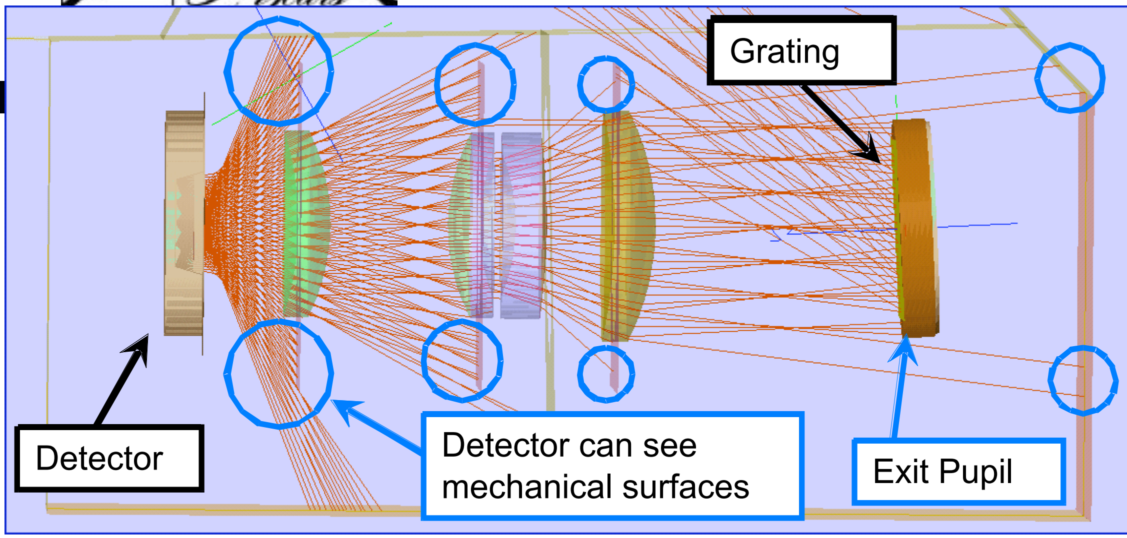
SIRAS-G Measured Spectra

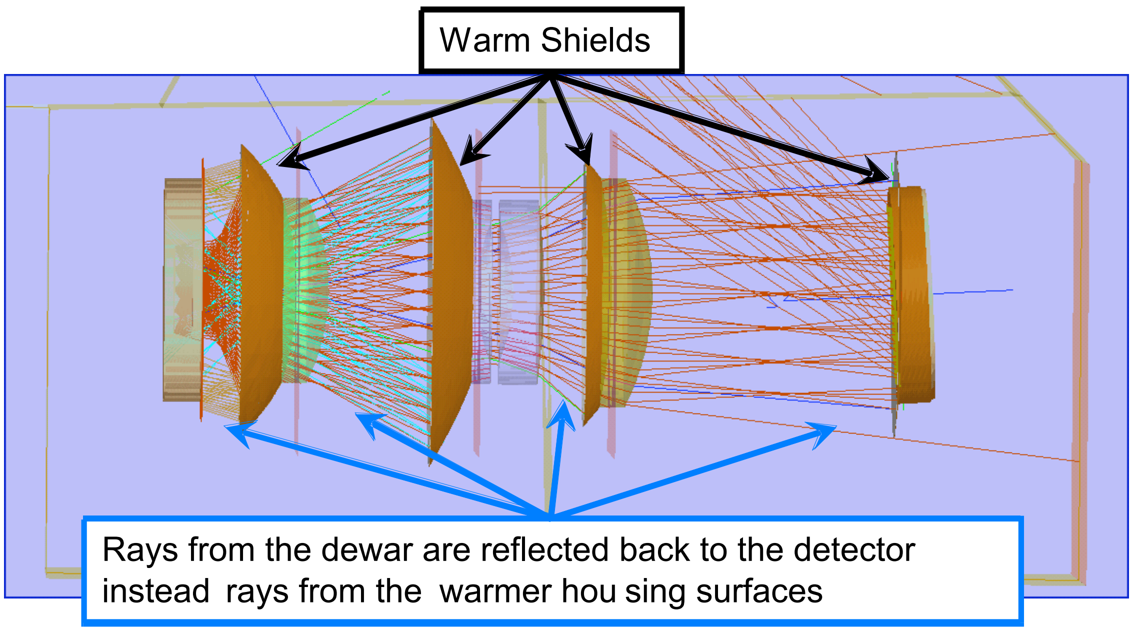
Warm Shield Implementation



- Lab Demo demonstrated feasibility of Multi-Stage Warm Shields
- High performance warm shield eliminates need for true cold shield
- This is the first known application of warm shields to IR imaging spectrometers
- Mature design methodology in place to support warm shield designs for additional wavelength ranges, etc.
- Design, geometry and warm shield positioning well understood for extrapolation to other spectrometers
- Excel spreadsheet provides insights into sensitivities
- Test methodology for validating warm shield performance under development

What's a Warm Shield? And, Why Use it?

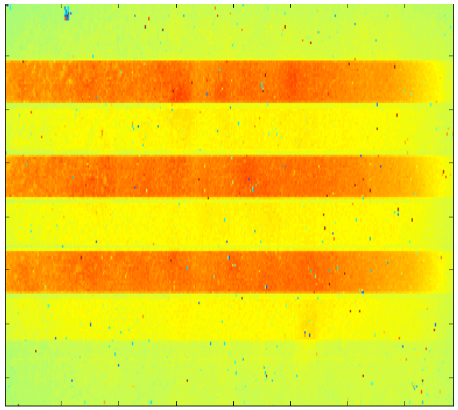




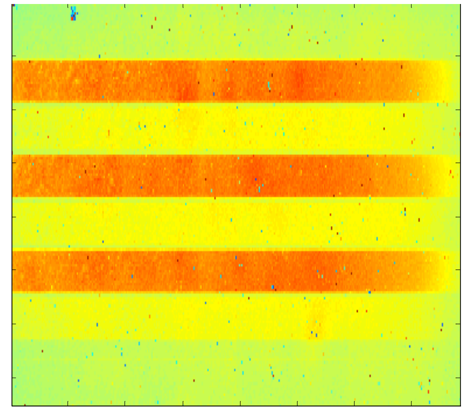
- SIRAS-G do not have a cold stop in the traditional sense of locating the stop at the detector dewar.
- The stop is located at the gratings because that improves the control of the spectrometer distortions (keystone and smile)
- Not having a cold stop introduces thermal background seen by the detectors
- This can be reduced by:
  - Using warm shields
  - Reducing the temperature of the cavity
- Multi-stage warm shield concept originally developed on SIRAS-G

Impact of Using Warm Shields (LWIR Pathfinder)

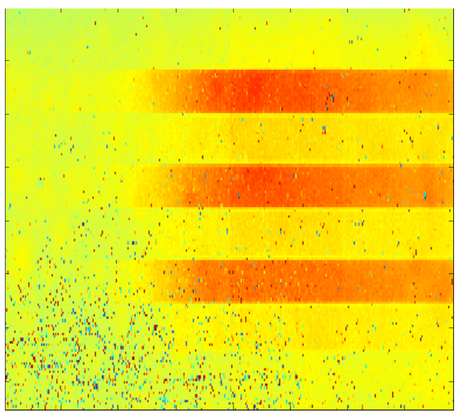
Ch 1, Cycle 4
T~= 112.9 K



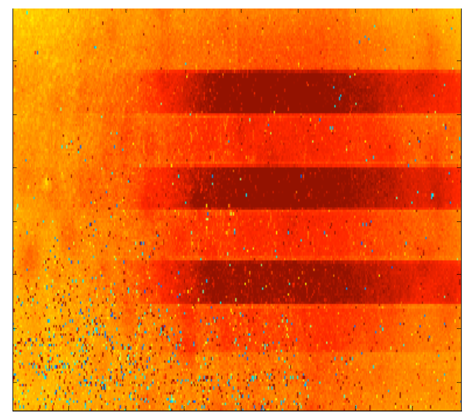
Ch 1, Cycle 4b
T~= 112.6 K



Ch 2, Cycle 4
T~= 112.9 K



Ch 2, Cycle 4b
T~= 112.6 K



- **Channel 1 and 2 data sets from cycle 4 and 4b. Channel 1 is largely unchanged and channel 2 has much higher near field thermal background**

Radiative Transfer Tools Developed to Provide Insight to Instrument Performance

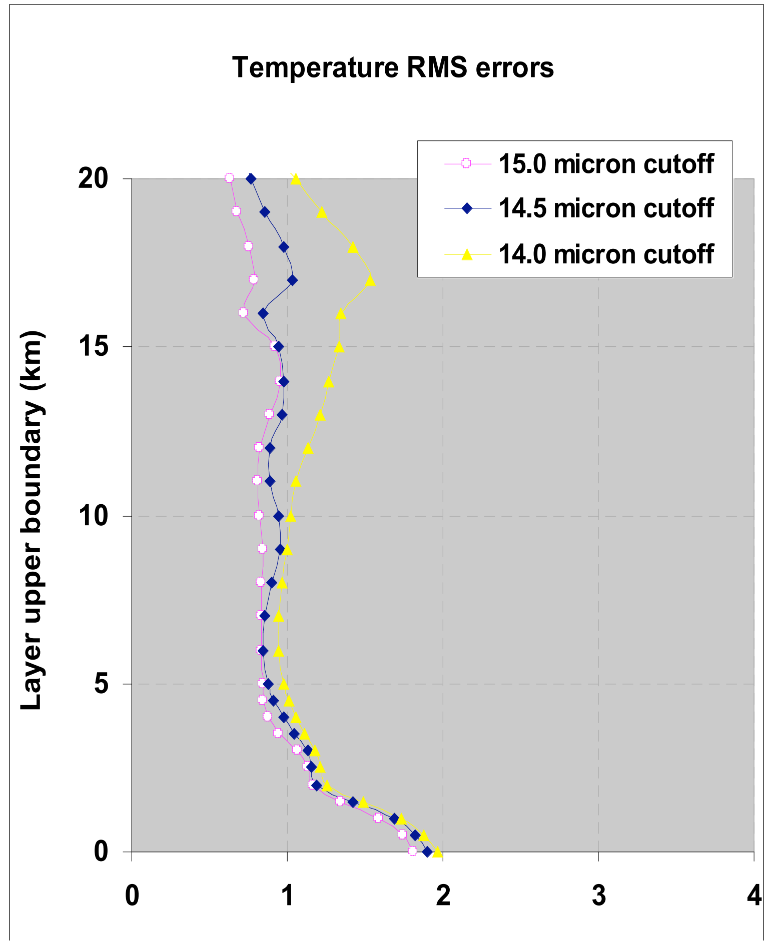
Example: Impact of LW Cutoff on Temperature Sounding

Objective:

- Evaluate the impact on retrievals of reducing FPA performance or eliminating channels near 15 μm
  - Advantage is potential reduction in cost and/or technical development
  - These channels have greatest sensitivity to temperate in upper troposphere and lower stratosphere (UT/LS)

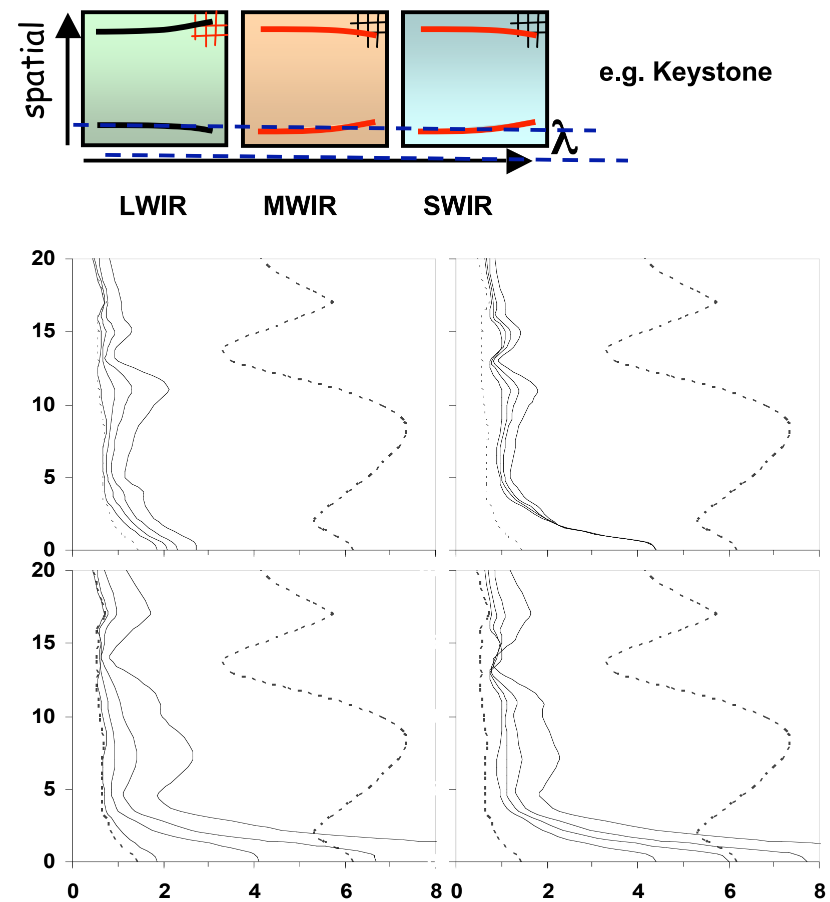
Results:

- 0.2K improvement in upper troposphere (<220 mb) and lower stratosphere with 650 cm^{-1} cutoff
- No significant additional temperature information is obtained with inclusion of the SMW (1650-2250 cm^{-1}) water vapor band
  - *< 2250 cm^{-1} region only sensitive to low level temperature*
  - *> 2250 cm^{-1} could improve UT/LS temperature but problem with NLTE in 4.3 μm region*



Spectrometer Co-registration Errors

- For an ideal imaging spectrometer, all spectral channels would see the same ground pixel at the same time
- Optical distortion, FPA-to-FPA mechanical alignment errors and relative magnification errors in camera optics can lead to misregistration of channels
- In regions where strong scene gradients exist (e.g. near clouds), registration errors produce spectral artifacts by mixing spectra from neighboring pixels
- The spectral errors are not random noise in the measurement but are correlated across the band affecting science data in a complex way
- ***The impact of spectrometer registration errors on science data must be quantified using an end-to-end measurement simulation approach***



Temperature retrieval errors

Candidate LEO Mission Parameters

- First mission being studied is an AIRS Follow-On Mission
  - Low-Earth Orbit; enhanced spatial resolution
  - Mission focused on retrieval of atmospheric temperature profiles, water vapor profiles, ozone column and cloud properties
  - Spectral coverage and resolution optimized for these parameters

Candidate AIRS Follow-On Mission

Key Measurement Requirements:

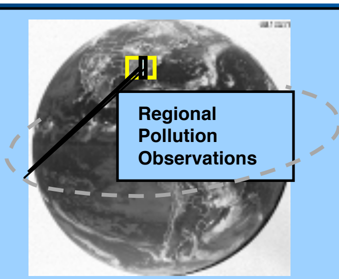
- Spatial resolution: 1-km
- Swath coverage: 1650 km (TBR)
- Radiometric Noise < 0.2K (TBR)

Measurement	Accuracy (req.'ed : goal)
Surface Temperature	1K : 0.5K
Temperature profiles	1K (rms) (1-km layers < 100mb)
Humidity profile	20% : 10% (2-km layers < 100mb)
Column Ozone	20%

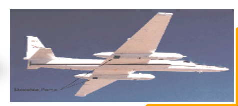
Measurement	Spectral Range (cm^{-1})	Min. res (cm^{-1})	Goal res (cm^{-1})	Notes
Temperature profiles	650 - 768 2228 - 2255 2380 - 2410	0.5 2.0 2.0	0.5	Higher spectral resolution improves T sounding throughout range
Humidity profiles	1370-1610	2.0	0.5	Weaker water lines near 2600 cm^{-1} used AIRS
Ozone Column	1001-1069	0.5	TBD	Very high resolution necessary for profile info.
Surface Temperature	750-1200	~1.0	0.5	Several channels: 750-1235 cm^{-1} and >2400 cm^{-1}
Dust properties	750-1200	~1.0	0.5	Higher resolution improves UT/LS retrievals
Cloud properties	750-1200	~1.0	0.5	3 channels: 8,10,12 mm

Coordinated Path to Space-Flight Programs

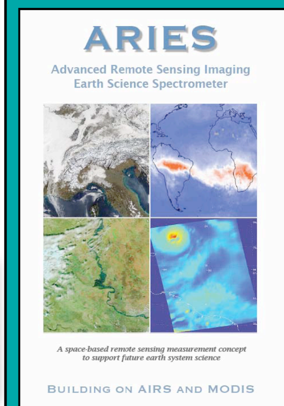
Air Pollution & Chemistry from GEO
- Notional Mission Requirements:
- UV-VIS spectrometer: 310-600 nm
- Infrared spectrometer: 3.75-15 mm
- Spatial resolution 4-km
- Regional coverage in 6 minutes
- Disk coverage in 30 minutes
- Baseline concept developed under SIRAS-G IIP



Ball will be proposing an Airborne Demonstration of SIRAS-G for recent NASA ROSES AO

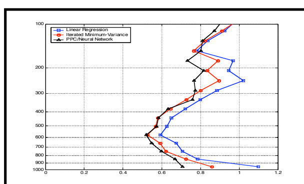


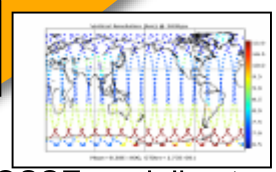
SIRAS Airborne Demo



ARIES (JPL)
- Enabling technology for ARIES
- Proposed by JPL, NOAA/NESIS, JCSDA, GSFC, UMBC) for Decadal Survey
- AIRS heritage
- “MODIS Spatial Resolution with AIRS Spectral Resolution and NEdT”
- 1-km footprint
- 3.6-15.4µm; 4800 channels; λ/Δλ =1500
- Pushbroom geometry is easily met using SIRAS technology
- Baseline concept being developed in conjunction with JPL

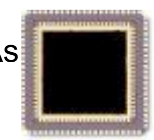
Instrument optimization Based on Science Requirements

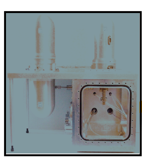




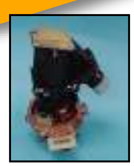
OSSE modeling to guide definition of instrument parameters based on retrieval sensitivities

Large Area FPAs

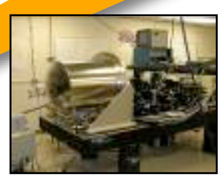




Active Coolers

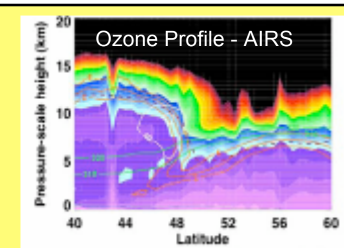


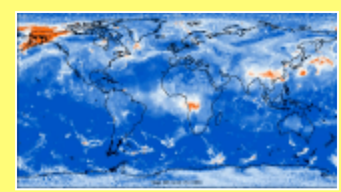
LWIR Spectrometer Demo SIRAS-1999



MWIR imaging Spectrometer Demo SIRAS-G 2006

AIRS Follow-On Instrument
- Low-Earth Orbit; enhanced spatial resolution
- Mission focused on retrieval of atmospheric temperature profiles, water vapor profiles, ozone column and cloud properties
- Spectral coverage and resolution optimized for these parameters
- Spatial resolution: 1-km
- Swath coverage: 1650 km
- Radiometric Noise < 0.2K
- Concept study documented in Tech Report 33130SYS-10 LEO Point Design





CO total column - AIRS

Increasing Technology Readiness & Science Capability

Laboratory | Airborne | Spaceborne

SIRAS-G Instrument Incubator Program
PI: Thomas Kampe, Ball Aerospace & Technologies Corp.

Objective

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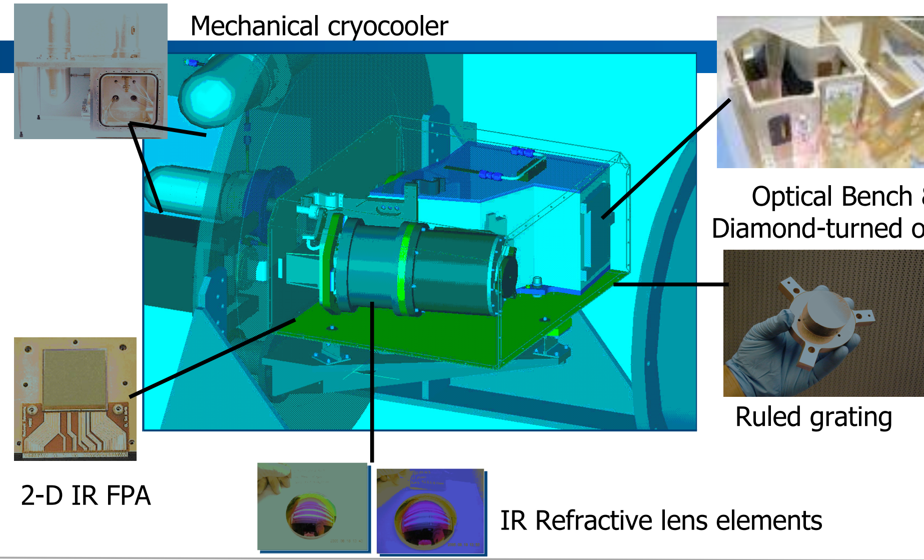
- **Validate operational performance in a laboratory demonstration**
- **Generate a design recommendation for space flight instrument**



Accomplishments

- **Radiative transfer forward-modeling tools & OSSE model developed to link instrument requirements/performance to science requirements & used for flight concept development**
- **Developed single-channel MWIR lab demo that integrates flight-like spectrometer, active cooling, flight-like IR FPA and electronics**
- **Spectrometer design developed for low distortion (spectral smile & keystone) & excellent image quality. Design form is extendable to multi-leg configuration (3-15 μm spectral coverage)**
- **Advanced technology multi-stage warm shield concept demonstrated**
- **Demo instrument tested in cryogenic environment using test methodology and apparatus developed on BATC IRAD (keystone distortion, smile, MTF, SRF, dispersion)**

Technology Development Partners
NASA/Jet Propulsion Laboratory

TRLin= 2 TRL current= 4